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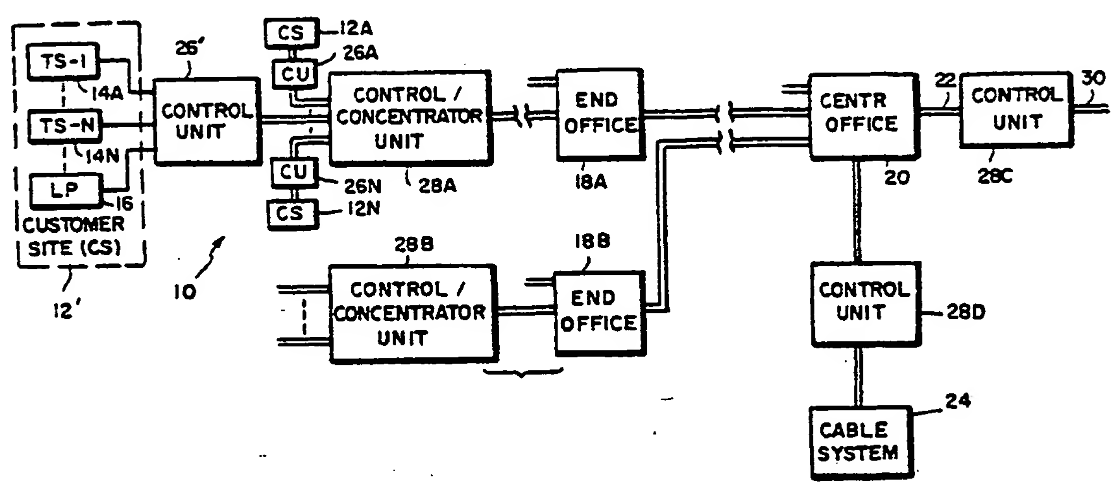

(57) Abstract

Management, control and monitoring/accounting of data flow in a digital transmission system is provided by control units at demarcation interfaces in the system. Such units provide a variety of functions, including policing data flow to control data rate through the interface, maximum burst length and types of data permitted to flow through the interface, monitoring and accumulation of data flow information which may be subsequently retrieved and utilized for accounting and other functions, grooming of information on a line to optimize line utilization while permitting timely access to the line for time-sensitive data, buffering traffic as required at the interface, performing a variety of housekeeping functions, synchronizing clocks at remotely located customer sites and assuring that idle cells in for example ATM transmissions are not surreptitiously utilized to transmit data.

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METHOD AND APPARATUS FOR CONTROLLING TRANSMISSION SYSTEMS

Field of The Invention

This invention relates to digital data transmission systems, and more particularly to methods and apparatus for managing, controlling and accounting for the flow of digital data through such systems.

Background of The Invention

As use of the "information highway" increases, with greater varieties of data being transmitted therethrough, and with an increasing variety of services being offered, the problems of policing and accounting for such uses become more difficult. In particular, current digital data networks normally allocate costs by having a customer purchase a line having a fixed total bandwidth, with the increments between bandwidths which a customer may purchase being relatively large. This arrangement presents a number of problems. First, it forces a customer to purchase a line, and pay the cost of such line, to meet maximum capacity when such capacity may be needed for only short periods. Second, the large differences between the bandwidth of the lines which are available frequently requires a customer to purchase a line having much more bandwidth than is required. As a result, utilization of many lines is at only a small fraction of the line's capacity.

Further, the information highway will result in data frequently being transmitted through transmission media owned by a number of different entities. For example, data may pass through the equipment of a customer onto copper lines of a local carrier, then onto fiber optic line of a long distance carrier and perhaps through a cable company lines

before reaching an end user. Satisfactory mechanisms to account for traffic carried by each carrier in a chain as data moves through a number of demarcation interfaces (i.e., junctions between transmission media which may be of different type and/or may be owned by different entities) create problems which have not yet been fully addressed.

Further, a potential advantage of the information highway is that users will able to obtain data appearing on the highway on demand. However, this can also present a problem in accounting for the information received and utilized.

Heretofore, all accounting has been done at the central offices or other facilities of telephone companies or other carriers and, as previously indicated, flat rates have frequently been charged for service eliminating the need for accounting. However, neither of these techniques is particularly efficient. Flat rates can result in users either significantly overpaying or significantly underpaying for services which they utilize; while accounting at a carrier office requires that all traffic go through such office, preventing types of service among small classes of users where installation of switch equipment is not feasible. It also requires that the carrier office be able to identify data as being from a particular customer which may become more difficult if a number of users share a single line in order to make more efficient utilization of lines. Requiring all accounting to be done at a carrier office therefore reduces system flexibility and will become increasingly complex as the number and variety of services being offered on the information highway increase.

The problem of policing the flow of information on the information highway is also complex. Traffic on the information highway typically falls into two general classes, information which is time dependent and will be distorted if

delayed during transmission, voice and video traffic falling into this class, and information which is not time dependent, such as the output from data processors. In order to make optimum use of the channels available for transmitting digital data, it is important that time dependent or isochronous data or other traffic be able to timely access a transmission line or other medium while still permitting optimum utilization of the line and avoiding overload of the line so as to minimize data loss. When such policing is performed at a carrier office, it is difficult to regulate the flow of data, particularly if there is more than one customer on a line connected to the office. For this reason, customers, particularly business customers transmitting digital computer data, are generally required to purchase dedicated lines to an office, frequently resulting in inefficient usage of the line.

A related problem arises from the fact that even though the clocks of a transmitting site and a receiving site may nominally be operating at the same rate, there are sufficient variations in such clocks to cause distortion of time dependent information. A need exists for more effective ways to assure that such clocks were in sync. Another problem is that the customer frequently has a variety of equipment which may be transmitting and/or receiving information, which equipment operates at different rates, and the rates for all such equipment generally is different from that of the line to which the customer is connected. It is therefore desirable, for optimum line utilization, that the data be accumulated and preferably formed into packets or cells which may be asynchronously outputted onto the line or asynchronously received from the line. A protocol which has been recently established for such asynchronous transfer of data cells is "asynchronous transfer mode" (ATM). With ATM,

data is formed into 53 byte cells, each of which includes a five-byte address and control header and up to 48 bytes of information. Existing ATM systems have all management performed by switching equipment at a carrier office.

Such management includes the establishment of connections with addressed sites, management of flow and the associated regulation techniques that attempt to insure the error free operation of the network. This includes various systems to regulate and to apply back pressure techniques in an attempt slow flow of cells as required to permit high priority data access to the lines and to avoid overload of lines. While such techniques are adequate when the flow of information is within a single homogenous network architecture, they do not work well for traffic flow through multiple systems, at least some of which may have different specifications. Another current problem with ATM systems is that parity checking is done only on the header, there being no facility for doing error checking on the data portion of a cell.

A need therefore exists for an improved system for controlling, managing and accounting for digital data flow through transmission systems. In particular a need exists for transmission systems which facilitate grooming of transmission lines to allow greater line utilization, which flexibly establish data flow limits, both in terms of average data flow and maximum burst length, which are able to accurately measure cell traffic or data use by a customer both in terms of egress and ingress, which are able to match varying data rates across demarcation interfaces and which assure timely access to the network and synchronous transmission and reception of time dependent traffic such as video and voice. Such techniques should be adapted for use in ATM or other cell/packet modes of data transfer and to permit for error detection on the data in an ATM cell.

Summary of The Invention

The above and other objectives are achieved in accordance with the teachings of this invention by providing for the management, control and accounting of data flow at the demarcation interfaces in a system rather than at carrier offices/switches.

More particularly, this invention provides for a control unit which may be located at the demarcation interface between a customer unit and a transmission system with which the customer site interfaces and for control units to be utilized at at least selected other demarcation interfaces in the system.

The control unit may perform a variety of functions including:

1) Policing traffic flow in at least one direction across the corresponding interface by for example limiting output data rate and/or the maximum permitted burst length for at least one type of data passing through the interface. The control unit may also be able to programmatically control the types of data permitted to pass through the interface.

2) Monitoring/accumulating information on data flow for accounting or other purposes.

3) Concentrating data from a variety of sources on a line so as to optimize line utilization while still assuring that time-sensitive information/data from all sources on the line are able to obtain timely access to the line. Such concentrating of data on a line is also sometimes referred to as "grooming" of the transmission line.

4) Provide buffering capability to match varying data rate or to perform other required functions to maintain compatibility between the systems/lines meeting at the demarcation interface.

5) Perform a variety of housekeeping functions including error detection, error correction, data scrambling and descrambling and various system maintenance functions.

6) Assure that the clocks at the transmission and receiving site for time-dependent data are in synchronization to prevent distortion of received data.

7) Prevent the use of idle or unassigned cells in ATM communication from being used to surreptitiously circumvent bandwidth limitations. Monitored data accumulated at a control unit may be interrogated and transmitted to a carrier office for accounting and/or other functions, thereby permitting customer billing based on actual use of a line rather than on a flat line charge and permitting much greater flexibility in billing procedures.

Policing of traffic flow may involve storing an indication of maximum permitted data flow rate in at least one direction through an interface and controlling the flow of data through the interface in the direction to prevent such flow rate from exceeding the maximum permitted flow rate. Typically, such control is exercised on data being outputted from equipment at a customer site. Where different classes of data having different priorities are being outputted from a customer site, the control unit can also prioritize data to assure that higher priority time-sensitive data or traffic is outputted ahead of lower priority data. Where data is being transmitted as cells of a substantially fixed length, such as for transmission of ATM cells, the spacing between cells, particularly low priority cells which are made available for transmission may be controlled and the control unit may also substitute an idle message generated at the control unit for any idle message generated at customer equipment, thereby preventing surreptitious use of idle cells for data transfer.

An additional problem dealt with by this system is that of providing a parity value to permit the checking of the data portion of ATM cells which are being transmitted as part of a SONET frame. This is accomplished by placing computed parity values for the information portion of an ATM cell in the next occurring reserved column in the SONET cell.

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention as illustrated in the accompanying drawings.

Description of Drawings

FIG. 1 is a schematic block diagram of an illustrative system employing the teachings of this invention.

FIG. 1A is a schematic block diagram of a single private system employing the teachings of this invention.

FIG. 2 is a diagram illustrating an ATM cell.

FIG. 3 is a schematic block diagram of an illustrative control unit in accordance with the teachings of this invention.

FIG. 4 is a schematic block diagram of a circuit suitable for use as the cell mux circuit in FIG. 3.

FIG. 5 is a schematic block diagram of a circuit suitable for use as the cell demux circuit in the control unit of FIG. 3.

FIG. 6 is a chart of an illustrative SONET frame as utilized to transmit ATM cells.

Detailed Description

FIG. 1 shows an exemplary data transmission system 10 which will be utilized to illustrate the invention. The system includes a plurality of customer sites 12A-12N and 12' located at remote sites which, depending on the system, may

be within a given business complex, city, state, country, other geographical subdivision or worldwide. As is shown for customer site 12', each customer site may have a variety of equipment generating information/data to be transmitted and/or receiving transmitted information/data. Some of the equipment may initially be generating information in analog form which is converted to digital for transmission and some of the digitally received data may be converted to analog for utilization by customer site equipment. In general, the customer site may be considered to have constant rate equipment which generally produces time-sensitive information, such equipment including equipment generating telephone or voice communication traffic and video traffic, illustrated in FIG. 1 by TS1-TSN sources 14A-14N, and variable rate sources such as data processing systems, which normally output or receive data in high speed bursts, illustrated in FIG. 1 by variable rate or low priority (LP) source 16. There may in fact be a plurality of variable rate equipment 16 at a given customer site.

Heretofore, each customer unit 12 has been connected to an end office 18 or other carrier office over a dedicated transmission line with each carrier office containing switching and/or other equipment to control the flow of data to and from the customer site over its dedicated transmission line. To the extent there was a need to police traffic flow from or to the customer site, this was also done at the carrier office. While normally a customer paid a flat rate for use of its line, to the extent accounting was required, for example of long-distance or toll charges, such accounting was also done at a carrier office. End offices might be connected to a central office 20 which also had switching and accounting capabilities (accounting frequently not being done at end office) and central office 20 might be connected to

other central offices through high speed transmission lines or other suitable media 22. While cable systems such as cable system 24 or other separate data transmission carriers typically operate their own parallel system, to the extent such systems interconnected so as to use some of the transmission media of system 10, this was generally done through a central office 20 having switching and data processing capacity. All accounting for use of existing systems is performed at a central office or other carrier facility.

One problem with this arrangement is that it requires all traffic to flow through an end office 18, central office 20 or other carrier facility. Thus, if units 12A and 12' wish to communicate with each other, they can do so only through end office 18A. As discussed earlier, this could result in inefficient line utilization.

Further, each customer site 12 requires a separate line into an end office 18. Since the utilization of its line by a given customer site may vary significantly with time of day, day of week, season and the like and since there are fairly wide variations between the bandwidths of available lines, this frequently results in a customer having to pay for far more line capacity than it requires and with line utilization being relatively low for extended periods of time.

Another potential problem is that where, for example, end offices 18A and 18B are part of one system, for example the system of a local carrier, while central office 20 is part of a different system, for example that of a long-distance carrier such as AT&T or MCI, or a central office 20 of a local carrier connects to other central offices through the facilities of a long-distance carrier, a need will increasingly exist to account for traffic flow across the

demarcation interface between the transmission systems. A need may also exist to buffer or police traffic flow between the systems. Such need may also exist for example at the demarcation interface between a cable system such as cable system 24 and that of a data transmission carrier with which it may be interfacing.

To deal with the problems indicated above, and for other reasons, in accordance with the teachings of this invention, a control unit 26 is provided at the demarcation interface between each customer unit and the line connected to such customer unit; and control units or control/concentrator units 28 are provided as required, at other demarcation interfaces in the system. In particular, for purposes of illustration, a control/concentrator unit 28A is shown at an interface where lines from customer sites come together to lead into a remote end office 18A and a control/concentrator unit 28B is shown at the interface for end office 18B. Unit 28A may, for example, be at a remote industrial park where it is not economically feasible to install switching equipment, but where there is a need to manage, control and/or account for traffic from a number of users to, among other things, enhance line utilization. Office 18B may, for example, be in a downtown neighborhood where many customers are nearby. Unit 28B may, at least in part, substitute for more expensive switching equipment at such office. The lines leading into a unit, such as unit 28A may, be of the same type as those coming out of the unit or may be of a different type, with for example copper wires leading into the unit and a fiber optic line interconnecting the unit to an office 18 or 20. Similarly, a control unit 28C is shown at the demarcation interface between for example a local carrier central office 20 and the high speed line 30 of a long-distance carrier. If the local carrier had only a single office 20, then only a

control unit 28C would be utilized while if a number of offices 20 where connected to line 30, a control/concentrator unit might be utilized. Similarly, a control unit 28D is shown at the demarcation interface between cable system 24 and the network of the local carrier. If other systems were also connected to unit 28D, it might also perform a concentrator function.

The various control units 26,28 may perform a variety of functions which include, but are no means limited to:

1) Policing traffic flow in at least one direction across the corresponding demarcation interface. Thus, the unit might limit the output data rate and/or the maximum permitted burst length for at least one type of data passing through the interface in at least one direction. The unit may also be able to programmatically permit certain types of data to pass through the interface while rejecting and blocking other types of data. Thus, a carrier office may be able, by selectively sending maintenance messages, to control data which a given customer site is authorized to receive.

2) Accounting for information/data of at least selected type flowing in at least one direction through the interface. Thus, a customer may be billed based on actual usage of a line rather than based on a flat line charge, permitting much greater flexibility in billing procedures.

3) Concentrating data from a variety of sources on a line so as to optimize line utilization while still assuring that time-sensitive information/data from all sources on the line are able to obtain timely access to the line.

4) Provide buffering capability to match varying data rates or perform other required functions to maintain compatibility between the systems meeting at the demarcation interface.

5) Perform a variety of housekeeping functions including error detection, error correction, data scrambling and descrambling and various system maintenance functions, including switching to a redundant line in the event of equipment or line failure.

6) Assure that the clocks at the transmission and receiving site for time-dependent data are in synchronization to prevent distortion of received data.

7) Prevent the use of idle or unassigned cells in ATM communications, particularly those between customers on a private line, from being used to surreptitiously circumvent bandwidth limitations on the line by having data inserted in their payload or information fields.

FIG. 1A illustrates an alternative mode of operation which is possible utilizing the teachings of this invention wherein two customer units 12X and 12Y communicate directly with each other over, for example, lines 32 which may either be dedicated lines for communication between sites 12X and 12Y or may be part of a network, for example a private communication network interconnecting various remote sites of a single customer. A control unit 26X,26Y is provided for each corresponding customer unit to control, manage, and account for traffic flow in either or both directions for the corresponding site. The teachings of this invention thus permit full control and accountability on a multisite private communications system without the added expense of a carrier office or switching equipment.

In the following discussion of an exemplary control unit 26, it will be assumed that such control unit is being utilized in conjunction with the transmission of asynchronous transfer mode (ATM) cells. FIG. 2 is a diagram illustrating the cell structure of a standard 53 byte ATM cell. The cell includes a five byte header which contains, among other

things, the address to which the cell is being directed and 48 bytes of payload or user information. Of the five bytes in the header, the first four bits of the first eight-bit byte contain a generic flow control field (GFC) which is used to control the flow of traffic across the demarcation interface between a customer and the network. The next 24 bits, the last half of byte 1, bytes 2 and 3, and the first half of byte 4, make up the ATM address for the cell. This three byte field is divided into two subfields. The first byte contains a virtual path identifier (VPI) and second two bytes make up the virtual channel identifier (VCI). In ATM, a virtual channel is a connection between two communicating ATM entities and may consist of a number of ATM links across several systems and interfaces. Virtual paths are a group of virtual channels carried between two points and may also involve passage through many systems and interfaces. The next three bits indicate payload type (PT) for the information carried by the cell. These bits may for example be used to indicate voice or video data as well as operations and maintenance messages. At this time values 0-3 are reserved for identifying various types of customer data, 4 and 5 indicate management information, with 6 and 7 being reserved for future definition. The last bit of byte 4, the CLP bit, indicates cell loss priority and is set by the user. The bit indicates the eligibility of the cell for discard by the network under congested conditions. For example, if this bit is set to one, the cell may be discarded by the network under conditions to be discussed later while if the bit is set to zero, the cell will not be discarded. The final byte is the header error correction (HEC) field. It provides protection against misdelivery of cells due to address errors. The remaining 48 bytes may be used for user information; however, up to four of these bytes may also be

used for various control functions, including error detection/correction and, as will be discussed later, clock synchronization for time-sensitive messages.

Referring now to FIG. 3, sources 14A-14N and 16 are shown as being connected to a multiplex-demultiplex (MAD) unit 40. Unit 40 has a cell multiplexer 42, with the output lines from each source 14 and 16 being connected as inputs to each of the sources being received from the demultiplexer. Unit 40 also has a transmission interface 46 through which the external transmission medium 48 interfaces with multiplexer 42 and demultiplexer 44. Transmission interface 46 performs certain cell delineation, header error correction and payload scrambling and descrambling functions which are basically housekeeping functions not directly related to the objectives of this invention. Finally, the MAD unit 40 interfaces with a FIFO memory 50 which is a random access memory (RAM), and also interfaces with a control processor 52 which may for example be a microprocessor chip or other suitable processor designed or programmed to perform the various functions hereinafter discussed.

FIG. 4 shows a circuit suitable for use as cell multiplexer circuit 42. Referring to FIG. 4, low priority data is received on line 60 from low priority source 16. Data on line 16 may be received from one or more such sources. The data on line 16 is passed through suitable error detection/correction circuitry which may involve parity checking and other appropriate error detection/correction techniques. The data is then passed through a shift register 64. When the five-byte header of a cell is in this register, address comparator 66 is clocked by a signal on line 58 to perform a comparison between the address in the cell header and addresses in address table 70. If it is determined that

the address of the header 64 corresponds to an invalid address in address table 70, for example the address of a time-sensitive source 14, or some other address to which the low priority source is not authorized to transmit, a match output is obtained on line 72 which is applied to cell filter and peak rate policing circuit 74. The signal on line 72 inhibits circuit 74 from generating an INCLK output on line 76 to memory control 78. Since the INCLK is required for memory control 78 to pass an LP cell to FIFO memory 50, the signal on line 72 results in the cell having the invalid address header being discarded. A signal on line 72 also causes control circuit 74 to generate an output on line 80 which is applied to increment the count in address error counter 82. Counter 82 thus keeps track of the number of cells which are discarded due to an address error.

Circuit 74 is also operative to control the peak rate at which cells of LP data are applied to FIFO memory 50. This is achieved by requiring that there be a predetermined number of cells which are idle or nonassigned between each assigned cell. This number, which may be programmably controlled, is stored in intercell count register 84. INCLK signals are generated on line 76 only after the number of intercell counts have occurred between cells, thereby controlling the peak rate at which cells are applied to FIFO memory 50. If an effort is made to apply a cell to the FIFO memory when a clock is not appearing on line 76, the cell is discarded and circuit 74 generates an output on line 86 which increments the peak policing discard count in counter 88. Unassigned cells are also detected and discarded and a count is kept either separately or in counter 88 of such discarded cells. The peak policing discard function may be disabled either by setting the intercell count in register 84 to zero or by storing a suitable bit in this control register which is detected by circuit 74.

If a clock appears on line 76 when a cell is on LP data line 90, the cell is clocked through memory control 78 and written through data lines 92 into the address indicated on line 94 in FIFO 50. Memory control 78 alternates between enabling write line 96 and read line 98 for memory 50. If memory control 78 determines that FIFO 50 is full when a cell is received to be written therein, the cell is discarded and memory control 78 increments the cell discard count in counter 100.

When memory control 78 determines that FIFO 50 has an LP cell loaded which is ready for transmission, it generates an output on line 102 which is applied as one input to AND gate 104. The other input to AND gate 104 is a nonzero output on line 106 from cell credit counter 108. A signal appears on line 106 only when there is a nonzero cell credit count in register 108. Cell credit register 110 has stored therein a value indicative of the number of cells per unit of time or per number of cells transmitted which are permitted to be LP cells. The cell clock is applied to programmable divider 112 which generates a load output on line 114 to cell counter 108 after a programmably controllable number of cells have passed since the last load output. This permits the output rate of LP cells to be controllable both as to the number of cells permitted per cell interval and as to the length of such cell interval. As will be discussed later, the count in cell credit counter 108 is decremented each time an LP cell is transmitted.

When both inputs to AND gate 104 are present, a signal appears on line 116 which is applied as one of the polled inputs to polling state machine or circuit 118. The other poll inputs to machine 118 are signals which appear on lines 120 when the corresponding source 115 has a cell to transmit and a maintenance-ready signal on line 122 which is generated

by maintenance cell read control circuit 124 when maintenance cell register 126 has a maintenance cell to transmit. Polling state machine 118 polls the lines 116, 120 and 122 in order of priority with the lines 120 being polled first, followed by maintenance ready line 122 and finally LP ready line 116. If one of the TS sources 14 has a message ready to transmit, polling state machine 118 generates a clock output on the appropriate clock output line 128 to cause the appropriate source 14 to transmit the cell on the appropriate one of the TSN data lines 130. Machine 118 also generates an appropriate output on lines 132 to multiplexer 134 to set the multiplexer to pass the cell on the appropriate one of the lines 130 to multiplexer output lines 136. It should at this point be noted that cells are transmitted in byte-parallel form or in other words eight bits at a time. The bytes on lines 136 are stored in register 138 and are clocked out onto the output line of transmission media 48 from register 38 under control of signals on a line clock input 140. Register 130 thus permits matching of the bit rates between the customer unit and transmission medium 48 and assures that cells are synchronously applied to the line. In ATM transmission, this is important since each cell interval on the line has either an active cell or an idle cell and the identification of cell boundaries on the line could be lost if cells are not synchronously applied to the line.

If none of the TS sources 14 have a cell to transmit and there is a signal on maintenance ready line 122, polling machine 118 generates an output on maintenance clock line 142 which is applied to maintenance cell read control 124 to cause the maintenance cell stored in register 126 to be applied to multiplexer 134. At the same time, circuit 118 generates an output on line 132 causing multiplexer 134 to pass the maintenance cell to output lines 136.

If there is no signal on either a line 120 or a line 122 when polling state machine 118 is polling, and there is a signal on line 116, the polling machine generates an output on LP clock line 144 and also generates an output on line 146. The signal on line 144 is applied to memory control 78, causing the memory control to read out the oldest cell stored in FIFO memory 50 through data line 92 and to apply this cell through lines 148 to multiplexer 134. At the same time, signals appear on line 132 causing the multiplexer to pass the cell on line 148 to output lines 136. The signal on line 146 is applied to cell credit counter 108 to decremented this counter by one cell and is applied to LP cell counter 150 to increment the count in this counter by one. Counter 150 thus keeps track of the number of LP cells which have been transmitted.

Finally, if there is no signal on any of the lines 116, 120 and 122, polling machine 118 generates a default output on idle clock line 152. This clock is applied to idle cell read control circuit 154 to enable this circuit to pass the cell stored in idle cell register 156 onto lines 158 leading to multiplexer 134. The signals on line 132 at this time enable multiplexer 134 to pass the idle cell to line 136.

While it is possible for idle cell register 156 to only contain a cell header which would be set to all zeros for an idle cell in current ATM operation, it is preferable, particularly where there is a direct line between customer sites 12 (see FIG. 1A), for this register to contain an entire idle cell which is placed on output line 48 in lieu of any idle cell which may be generated by the user. This assures that the user does not utilize idle cells to transmit user information, thereby defeating the bandwidth limitations which the customer has accepted and paid for. The discarding

of inactive cells (i.e. cells which do not have an address header) by circuit 74 also defeats this potential opportunity to exceed agreed bandwidth limitations.

Processor 52 is capable of programmatically altering various values stored in cell mux circuit 42 and of interrogating and obtaining information from various counter registers in circuit 42. In particular, the data and address lines 160 and 162, respectively, for processor 52 are utilized to address various tables, registers, counters and the like and to either provide data thereto or receive data therefrom. Thus, addresses may be added or deleted from table 70, the intercell count in counter 84 may be changed and/or a bit inserted or removed from the register containing this count to either permit or inhibit peak rate policing. The division ratio in program divider 112 may be altered and/or the cell credit in register 110 may be changed to alter the permitted bit rate for LP cells, a maintenance cell may be written into maintenance cell register 126 and an appropriate idle cell or idle cell header may be read into register 156. Even though the idle cell or idle cell header would typically be all zeros, the programmable capability permits the system to accommodate any changes which may occur in the ATM protocol.

Similarly, the counts in cell discard counter 100, LP cell counter 150, address error counter 82 and peak policing discard counter 88 may be periodically interrogated and transferred to processor 52. Processor 52 may utilize each of these counts to generate a maintenance cell which may then be transmitted to a carrier office or other central location where these values are utilized for accounting or other purposes. It is also possible for processor 52 itself to have certain processing capabilities so what is transmitted to the carrier office may be a value obtained utilizing the

read out contents of the counters rather than the counts themselves. Each counter is reset when its contents are read out.

FIG. 5 shows a cell demultiplexer circuit suitable for use as the demultiplexing circuit 44. Referring to FIG. 5, line or media data received on lines 48 are stored in registers 170 and are clocked out from registers 170 under control of cell clocks from control unit 26. Cells outputted from register 170 pass through error check and correction circuitry 172 to assure the integrity of the data passing through the line, with signals at the output from circuit 172 being passed through shift register 174. When, as a result of clock inputs on line 176, address comparators 178 determine that a cell header is in register 174, the contents of register 174 are compared against the addresses stored in address tables 70 to determine if the cell is addressed to one of the TS sources 14, or whether the cell is a maintenance cell. For a preferred embodiment of the invention, if the cell is not for a TS source or a maintenance cell, it is assumed to be an LP cell and is transmitted to an LP source. If for some reason the LP source determines that the cell is not appropriate, the cell is discarded. Alternatively, a determination could be made at address comparators 178 as to whether the cell is for an LP source at the customer site and direct messages to an LP source only if the message is suitably addressed, messages not suitably addressed being discarded. Thus, by controlling the addresses in address tables 70, processor 52 can control messages which the customer site is authorized to receive and can block or reject messages which the site is not authorized to receive.

The outputs from address comparators 178 are applied through lines 180 to address and control logic 182 which, in response to the signals on lines 180 and to clocks received on lines 184, generates appropriate outputs for routing the data cell on line 186. In particular, the logic generates clock outputs on lines 188 which are passed through decoder 190 to appropriate clock lines depending on the signals on output lines 192 from logic 182. Thus, if the cell is for a TS source, the clock appears on the appropriate one of the TS clock line 194 which is applied to enable the corresponding source 14 to receive the data and a signal also appears on an appropriate one of the TSN address lines 196. Lines 196 are optional and are used to address the appropriate TS source 14 if only a single TS clock appears on lines 194. However, if there is a separate TS clock line 194 for each source, address lines 196 are not required. A signal also appears on line 198 for the first byte of the cell, which signal is applied to the appropriate receiving source.

Similarly, if the message is a maintenance message, a signal appears on maintenance clock line 200 which enables maintenance cell write control 202 to store the cell appearing on line 186 in maintenance cell register 204. Finally, if the message is determined to be message for an LP source, a signal appears on LP clock line 206 which is applied to the LP source to enable it to receive the cell on line 186. Each time a valid LP cell is received, logic 182 generates an output signal on line 207 which is applied to increment the count in LP receive cell counter 208. A count of received LP cells is thus maintained which may be utilized for accounting or other purposes.

As with cell multiplexer 42, signals on data and address lines 160 and 162 from processor 52 may be utilized to write new addresses into address table 70 or to remove addresses

therefrom, to interrogate counter 208 to receive the cell count therein, the counter being reset when this occurs, and to receive a maintenance cell stored in register 204. Processor 52 may perform a variety of functions in response to a received maintenance message.

FIG. 6 illustrates a basic SONET frame which may be utilized for transmitting ATM cells over a fiber optic transmission medium. Such transmission line may for example be used to connect a user site to a carrier office, for interconnecting carrier offices or the like. The basic SONET STS-1 frame contains 90 nine byte columns with four columns being utilized for transport and path overhead and the remaining columns or bytes being utilized for data. However, in such a frame, bytes or columns 39 and 50 are reserved or restricted fields which are not currently utilized. As shown in FIG. 6, 53 byte ATM cells are packed end-to-end on the rows or lines of the data portion of the SONET frame. With 84 available byte positions on each line, a little over fourteen ATM cells can be packed into a SONET frame. While in FIG. 6 the first ATM cell is shown as beginning in byte position 5 of the first line, it can be seen that the last frame extends over into the next SONET frame so that the cells in fact need not begin in the first byte position of a frame.

One problem with transmitting ATM cells is that, while parity or other error checks are performed on the header portion of ATM cells so transmitted, there is no provision for inclusion of a parity (i.e. BIP8) value for the data portion of such cells. This makes estimation of error rates for performance of the lines carrying ATM cells difficult to estimate. One feature of this invention is a method to tag the information bytes of the ATM cell by use of the restricted columns (30 and 59) of the SONET frame. In

particular, a parity or BIP8 value is calculated across the 47 or 48 information bytes of each ATM cell and this parity value is transmitted through the SONET channel by placing it in the next available reserved byte position after the end of the corresponding cell. Thus, for the first ATM cell shown in FIG. 6, the parity value would appear in the byte position of column 59 bearing the reference numeral 220. Similarly, the parity value for the second ATM cell would appear in the byte position of column 30 bearing the reference numeral 222. The numbers work out so that there is only one byte position in columns 30 and 59 in which a parity value could appear for each ATM frame. For the last cell of a given frame, the parity value would appear in column 30 on the first line of the next frame.

At the receiving end, the parity value for the received data portion of the cell is calculated and compared with the value transmitted for the cell in the reserve byte position. Errors may be accumulated and reported in the same manner such error information is currently accumulated and reported for addressing errors in the header portion of the cells. Other techniques for providing the information parity values, such as a dedicated BIP8 cell for every 47 or 48 cells transmitted, might also be possible.

As was mentioned earlier, it is desirable that both the data rate and maximum burst length for low priority data be controlled so as to facilitate the timely application of time-dependent or other high priority data to a transmission line. The multiplex unit shown in FIG. 4 illustrates several means for controlling the data rate. Further, since it is assumed that ATM data is being transmitted, burst length is inherently controlled so long as there is a separation between successive ATM cells. In FIG. 4, control 74 assures that there is a space between low priority or data cells so

long as the intercell count in counter 84 is nonzero. In applications where data is not being transmitted as packets or cells of controlled or fixed length, additional circuitry may be required in multiplexer 42 to control maximum burst length. This could for example involve another input to cell filter 74 from a maximum burst length register, the contents of which could be controllable from processor 52. The burst length of a transmission would be counted and compared against the maximum burst length value, with filter control 74 terminating a data transmission when the maximum burst rate is reached.

While only a control unit 26 has been described in detail, control units or control/concentrator units 28 would be similar, but might vary somewhat, particularly in the programming of microprocessor 52, depending on application. For example, the multiplexer 42 of control unit 28B would function primarily to keep count of cells passed therethrough and to buffer and control the transfer of information/traffic from the cable system to the telephone network. The demultiplexer might perform similar functions.

Control unit 28C would perform similar functions. Further, to the extent traffic was being received on line 30 from other sources, unit 28C might also function to control the traffic rate, maximum burst length and/or spacing between data which is permitted to be applied to high speed line 30. A buffering unit such as FIFO memory 50 could function to retain data to permit such control to be effected. Registers such as registers 138 and 170 might be used to buffer the data rate difference which may exist between the lines being interfaced at control unit 28C or additional FIFO memories may be provided for this purpose.

Control/concentrator units 28A,28B perform many of the same functions as the other control units depending on application. However, these units also perform the function of interleaving received data from the various customer sites so that time-sensitive data from sources 14 at each site are given priority and are timely applied to the output line from the unit. This involves recognizing from for example the CLP bit in each cell, or from some other area of the header, whether the cell is a time-sensitive cell which must be given high priority or a low priority cell. To the extent high priority cells arrive from any of the customer sites, they are passed to the output substantially as received. The data rate of such cells is typically low enough so that interference between them should not be a problem so long as use of the lines leading into the unit are not oversubscribed. The policing function of control units 26 at each customer site limit and space traffic arriving at the concentrator unit, thereby simplifying the concentrator unit function. Low priority cells from a source are passed on a FIFO basis to the output, with such cells being stored for example in a FIFO memory during periods when their transmission would conflict with the transmission of high priority traffic from another source. When there is no high priority traffic being received, low priority data is outputted, generally from a FIFO memory.

Typically, the permitted data rate for the various lines leading into a concentrator unit such as 28A,28B are limited so that the output line from the concentrator does not become oversubscribed. However, where one or more of the customer sites are not generating outputs or are generating little traffic for some period, this condition can be monitored by counters at the concentrator unit and this information used to generate a maintenance message either at the concentrator

or at a carrier office to temporarily permit higher data rates from other customer sites feeding into the same concentrator unit. Since the system enables accounting to be done based on line utilization, the added permitted usage, to the extent it is utilized, can be easily accounted for. When it is detected that traffic from the idle source is picking up, a maintenance message would be generated to return the other site or sites to their original data rate. To eliminate potential overload at the concentrator during transitions and to improve response time, control units 26 could be programmed to provide the suitable maintenance message when they are terminating or reinitiating transmission. The invention also permits for other suitable techniques to be utilized to further enhance line utilization without overload.

The demultiplexing function at concentrator units is more straightforward, generally involving only the distribution of traffic to the proper output and any buffering required to compensate for differences in line rate on the two sides of the unit.

As was discussed earlier, time-sensitive data generated for example at source 14A, may be transmitted through multiple systems, including private lines, local carrier lines, one or more long-distance carriers, the lines of another local carrier, etc. before finally being received at equipment 14 located at a destination site. While the ATM protocol provides for clocks at various customer sites to be operating at the same nominal rate, these clocks may in fact be operating at rates which vary by as much as 130 parts per million. Such lack of synchronization could cause distortion in the playback of time-sensitive information. Therefore, one of the control bytes in the information portion of an ATM cell typically includes a time stamp which is an indication

of the time variation from a central clock rate for the originating source. This time stamp is read at the receiving site and utilized to resync the clocks. In accordance with the teachings of this invention, the generation of the time stamp and the resynchronization may be accomplished in the control unit, the resynchronization being accomplished utilizing a phase lock loop.

Further, while FIG. 1 shows a single control unit at each customer site and a single transmission line interconnecting each customer site to an end office or other carrier office, in order to avoid loss of data and to provide high reliability, for preferred embodiments there are in fact two control units 26 at each customer site 12, each control unit being connected through a separate transmission medium to the appropriate carrier office. One of the control units and the corresponding transmission line are normally on line at a given time with a redundant unit and line on standby. When a defect is detected in the on-line control unit or the corresponding line, the units 26 at a given site are interconnected, preferably by a single line, in a manner such that operation is instantly shifted to the standby unit and the unit for which the defect has been detected is immediately removed from operation. This significantly enhances the error-free operation of the system.

While the invention has been described above with reference to preferred embodiments and various modifications of such preferred embodiments have been discussed, it is apparent that these embodiments and modifications are for purposes of illustration and that substantial further modification could be made within the teachings of the invention. Thus, numerous network configurations other than those shown in FIGS. 1 and 1A could be employed in practicing

the teachings of the invention, the control units 26 and 28 could be configured in other ways as required for a particular application, and various other components could be utilized for multiplexer 42 and demultiplexer 44. While ATM cells are being transmitted for preferred embodiments, this is not a limitation on the invention and other types of traffic, either in packet or cell form or in other form, could be transmitted with suitable modifications to the system. Further, while a microprocessor has been suggested for the processor 52, other processors, including special purpose hardware, might be used for performing this function or the functions of processor 52 might be an additional function performed by a processor contained at customer site 12.

Thus, while the invention has been particularly shown and described above with respect to preferred embodiments, the foregoing and other changes in form and detail may be made therein while still remaining within the spirit and scope of the invention.

WHAT IS CLAIMED IS:

CLAIMS

1. In a transmission system which transmits at least one class of data traffic between customer equipment located at a plurality of remote sites and other portions of the system, there being a demarcation interface between each remote site and the remainder of the system, control apparatus located at each demarcation interface comprising:

means for accumulating an indication of data transmitted in at least one direction through the demarcation interface; and

means for selectively retrieving the accumulated indications, the retrieved indications being usable for an accounting function.

2. Control apparatus as claimed in claim 1, wherein the control apparatus includes means for policing data which is permitted to flow through the demarcation interface in at least one direction.

3. Control apparatus as claimed in claim 2, wherein the means for policing includes means for indicating a permitted data rate output from the corresponding remote site through the demarcation interface for at least one class of data, and means for preventing an output data rate from said remote site which is in excess of said permitted data rate for the at least one class of data.

4. Control apparatus as claimed in claim 3, wherein said permitted data rate is an average data rate over a selected time interval.

5. Control apparatus as claimed in claim 3, wherein there are a first class of data and a second class of data, the first class of data having a higher priority than the second class; and

wherein the means for policing restricts only the second class of data to control the output data rate from the corresponding remote site.

6. Control apparatus as claimed in claim 5, wherein the second class of data originates from selected customer equipment at the remote site, and wherein said means for policing restricts data by preventing the control apparatus from accepting such data from the customer equipment.

7. Control apparatus as claimed in claim 2 wherein data is transferred between the remote site and other portions of the system over a transmission medium; and

wherein said means for policing includes means for selectively permitting data on said transmission medium to be accepted for receipt at the remote site.

8. Control apparatus as claimed in claim 2, wherein said means for policing includes means for indicating a permitted maximum burst length for data outputted through the demarcation interface from said remote site, and means responsive to the stored indication for controlling the maximum burst length of data outputted through the demarcation interface.

9. Control apparatus as claimed in claim 1, wherein data is transferred between the remote site and other portions of the system over a transmission medium, and including means at a carrier office for interrogating the

control apparatus over the transmission medium, means at the control apparatus for transmitting accumulated indications to the carrier office over the transmission medium, and including means at the carrier office for utilizing transmitted accumulated indications for a remote site to determine service charges for such remote site.

10. Control apparatus as claimed in claim 1, wherein customer equipment at the remote site output and receive data at first rates which may be different for various ones of the equipment, wherein there is a transmission medium operating at a second rate which is higher than said first rates on the side of the demarcation interface opposite the remote site, and wherein the control apparatus includes buffer means for matching said various first rates with said second rates for data passing across the demarcation interface.

11. Control apparatus as claimed in claim 1, wherein said data is transmitted as fixed-sized cells each of which contains an address header, and wherein said means for accumulating accumulates an indication of the number of cells transmitted in said at least one direction through the demarcation interface.

12. In a transmission system which transmits at least one class of data traffic between customer equipment located at a plurality of remote sites and other portions of the system, there being a demarcation interface between each remote site and the remainder of the system, control apparatus located at each demarcation interface comprising:

means for storing an indication of permitted data flow in at least one direction through the demarcation interface for the remote site; and

means responsive to said stored indication for policing data which is permitted to flow through the demarcation interface in said at least one direction.

13. Control apparatus as claimed in claim 12, including means responsive to a maintenance message received from another portion of the system through the demarcation interface for altering the indications stored in said means for storing, whereby policing of data flow in at least one direction for the remote site may be programmatically controlled.

14. Apparatus for controlling the transmission of data traffic across a demarcation interface comprising:

means at said demarcation interface for accumulating an indication of data transferred in at least one direction through the interface; and

means for selectively retrieving the accumulated indications, the retrieved indications being usable to perform an accounting function.

15. Apparatus as claimed in claim 14, wherein lines on opposite sides of said interface operate at different rates, and wherein said apparatus includes buffer means for altering the data rate of data received from one of the lines to match the data rate of the line receiving the data across the interface.

16. A method for transmitting parity values for the data portion of each ATM cell transmitted in SONET frame having a plurality of rows and columns, the ATM cells being packed end-to-end on successive rows of a data portion of each frame, said data portion having at least two spaced reserved columns in which data is not normally stored, the method comprising the steps of:

computing a selected parity value for the data portion of each successive ATM cell; and

placing the computed parity value for an ATM cell in the next available reserved column position after the end of the ATM cell from transmission with the SONET frame.

17. A method as claimed in claim 16 wherein the SONET frame is an STS-1 frame having 90 columns and nine rows, the reserved columns being columns 39 and 50.

18. A method for controlling and monitoring data traffic flowing in at least one direction through a demarcation interface between equipment at a customer site and a transmission system comprising the steps performed at the demarcation interface of:

a) storing an indication of maximum permitted data flow rate in said at least one direction through the interface;

b) controlling the flow of data through the interface in said at least one direction to prevent said flow rate from exceeding the maximum permitted flow rate; and

c) storing an indication of the data flow in said at least one direction through the interface.

19. A method as claimed in claim 18 wherein steps (a)-(c) are performed for data traffic passing from equipment at the customer site through the interface to the transmission system.

20. A method as claimed in claim 19 wherein equipment at the customer site generates a first class of data and a second class of data, with the first class of data having a higher priority; and including the steps of

(d) permitting data of the first class to pass through the interface when such data is available for transmission;

(e) permitting data of the second class to pass through the interface only when such data is available for transmission and there is no data of the first class available for transmission.

21. A method as claimed in claim 20 wherein steps (a) and (b) are performed only for the second class of data, step (e) therefore also requiring that the passing of the data of the second class available for transmission will not cause the maximum permitted data flow rate to be exceeded.

22. A method as claimed in claim 21 wherein maintenance data may also be passed through the interface to the transmission system, and including the step of:

f) permitting maintenance data to be passed through the interface only when such data is available for transmission and there is no data of the first class available for transmission, step (e) requiring as an additional condition for performance that there be no maintenance data available for transmission.

23. A method as claimed in claim 21 wherein data is passed through the interface in the form of cells of substantially uniform length, and wherein step (b) includes the step of controlling the spacing between successive cells containing data of the second class, which cells are made available for transmission.

24. A method as claimed in claim 23 including the steps of storing second class data cells which are available for transmission but cannot be transmitted is a FIFO memory, and

wherein step (e) includes the step of passing second class data cells through the interface from the FIFO memory.

25. A method as claimed in claim, 19 wherein data is passed through the interface in the form of cells of substantially uniform length, an idle cell of said uniform length being passed through the interface when a data cell is not available for transmission from the customer site, and including the steps of generating a predetermined idle cell, and permitting the generated idle cell to pass through the interface when there are no data cells available for transmission, no idle cell generated by equipment at the site being passed through the interface.

26. A method as claimed in claim 19 including the step of controlling the maximum burst length for data passing through the interface.

27. A method as claimed in claim 18 including the step of buffering data passing through the interface in at least one direction to facilitate matching of data rates on opposite sides of the interface.

28. A method as claimed in claim 18 including the steps of retrieving stored data flow indications, and passing data concerning retrieved data flow indications through the interface to a carrier office.

29. A method as claimed in claim 18 wherein data is passed through the interface in the form of cells of substantially uniform length, including the step performed at the interface for a customer site transmitting cells

containing time-sensitive information of generating a time stamp which is transmitted with the cell, and the step performed at the interface for a customer site receiving such cells of retrieving the time stamp and utilizing it to synchronize the clock at the receiving site with a clock at the transmitting site.

30. Apparatus for concentrating data traffic containing data having at least two different priorities, which data traffic is received on input lines from at least two different sources and is to be outputted on a common line, the apparatus comprising:

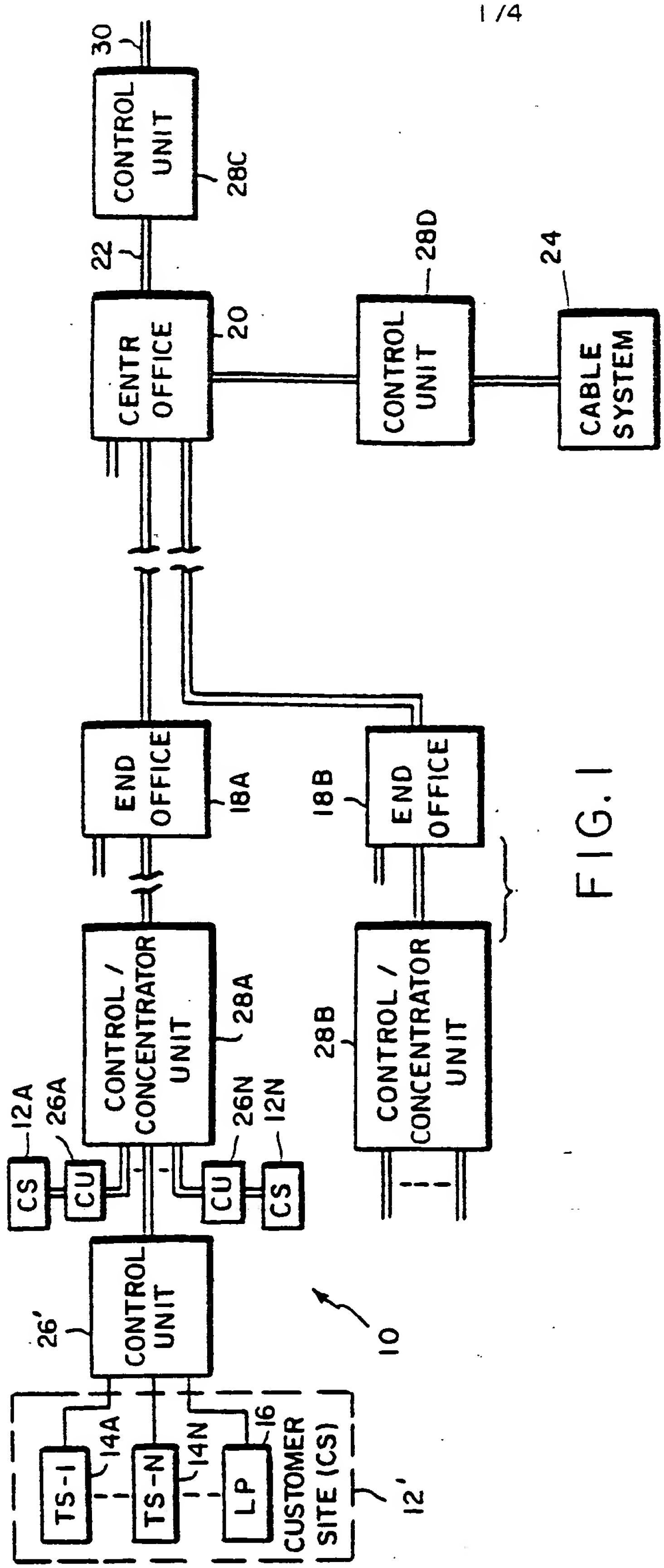
means for detecting the priority level of received data traffic on each of the input lines;

a FIFO memory;

means responsive to the detection by the means for detecting that received data traffic has a high priority level for outputting the traffic to the common line;

means responsive to the detection by the means for detecting that received data traffic has a low priority level for storing the traffic in the FIFO memory; and

means responsive to there being no high priority level traffic to be outputted for outputting low priority level traffic from the FIFO memory.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30
28C
22
CENTR OFFICE
20
CONTROL UNIT
28D
CABLE SYSTEM
24
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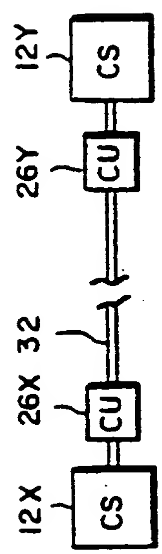
END OFFICE
18B
CONTROL / CONCENTRATOR UNIT
28A
CONTROL / CONCENTRATOR UNIT
28B
CS
12A
CU
26A
CU
26N
CS
12N
CONTROL UNIT
26'
10
TS-1
14A
TS-N
14N
LP
16
CUSTOMER SITE (CS)
12'

FIG. 1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26X
CU
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26Y
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12Y
CS

FIG. 1A

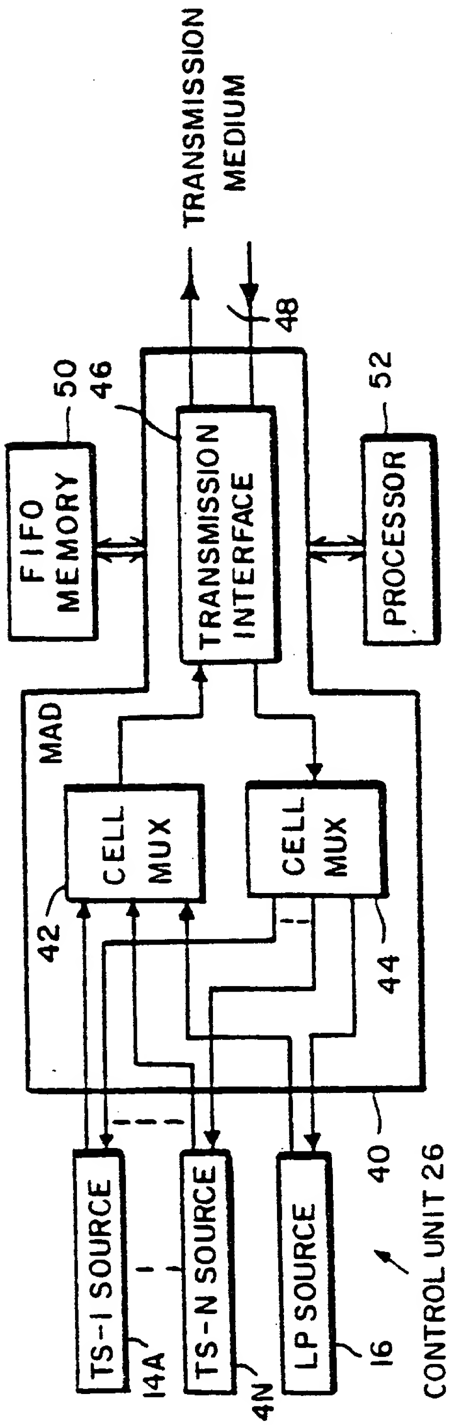


FIG. 3

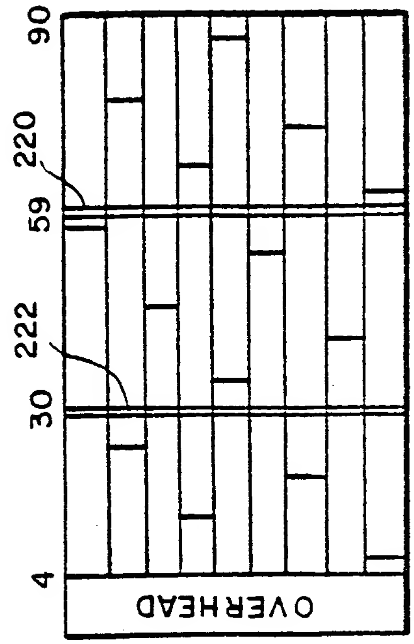


FIG. 6

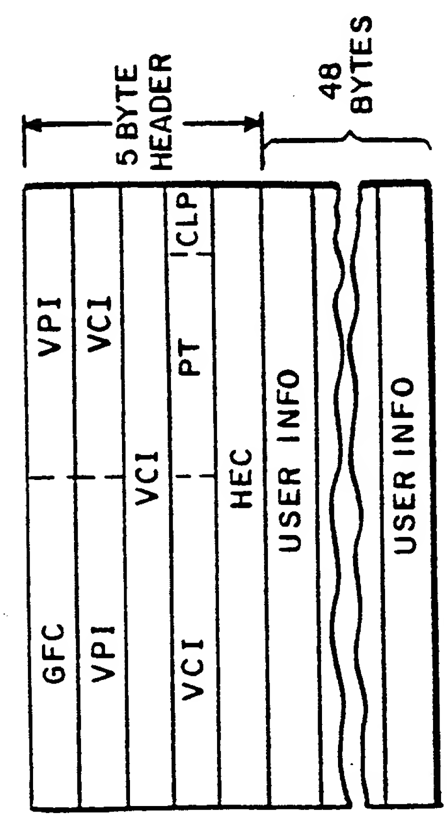
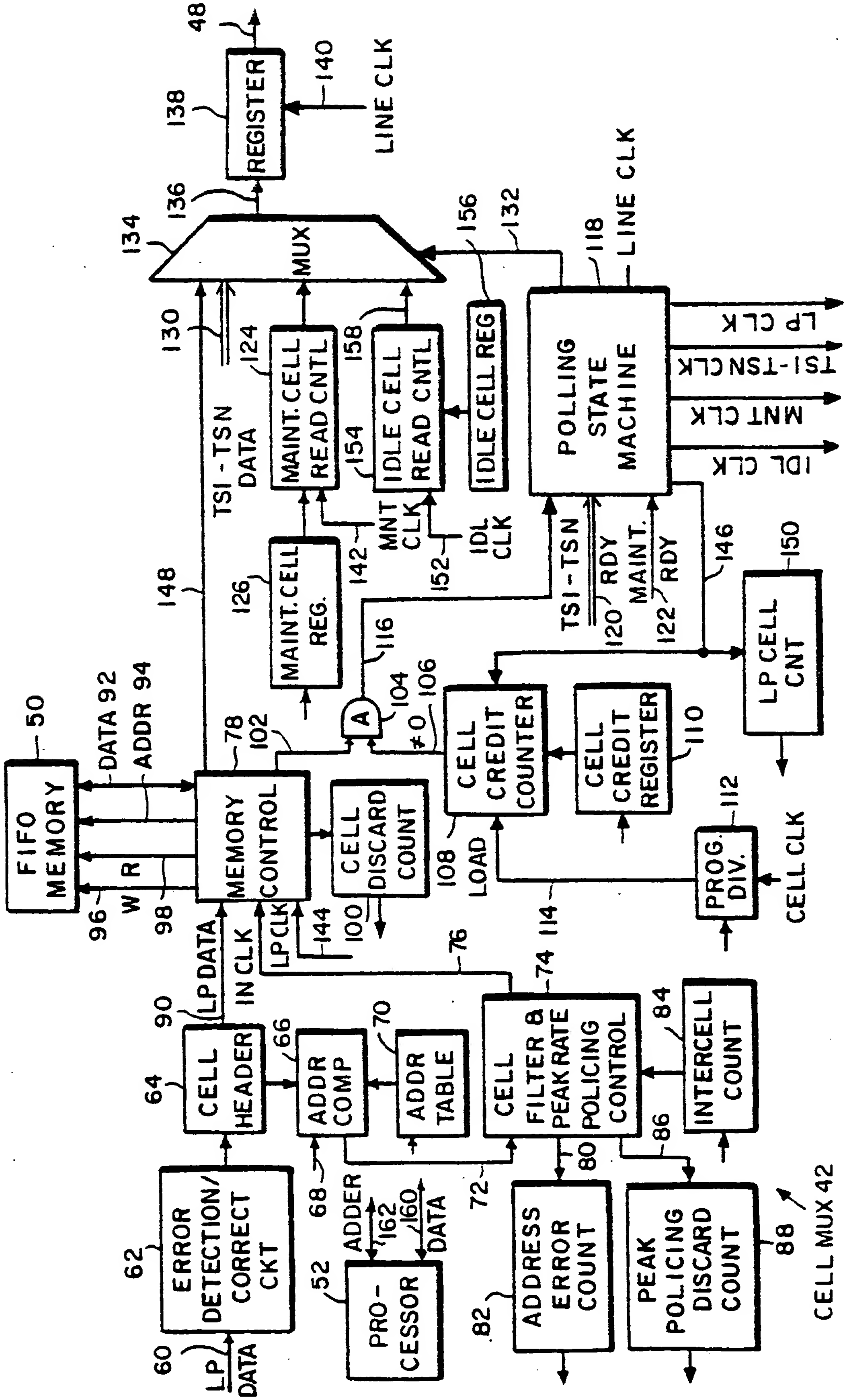


FIG. 2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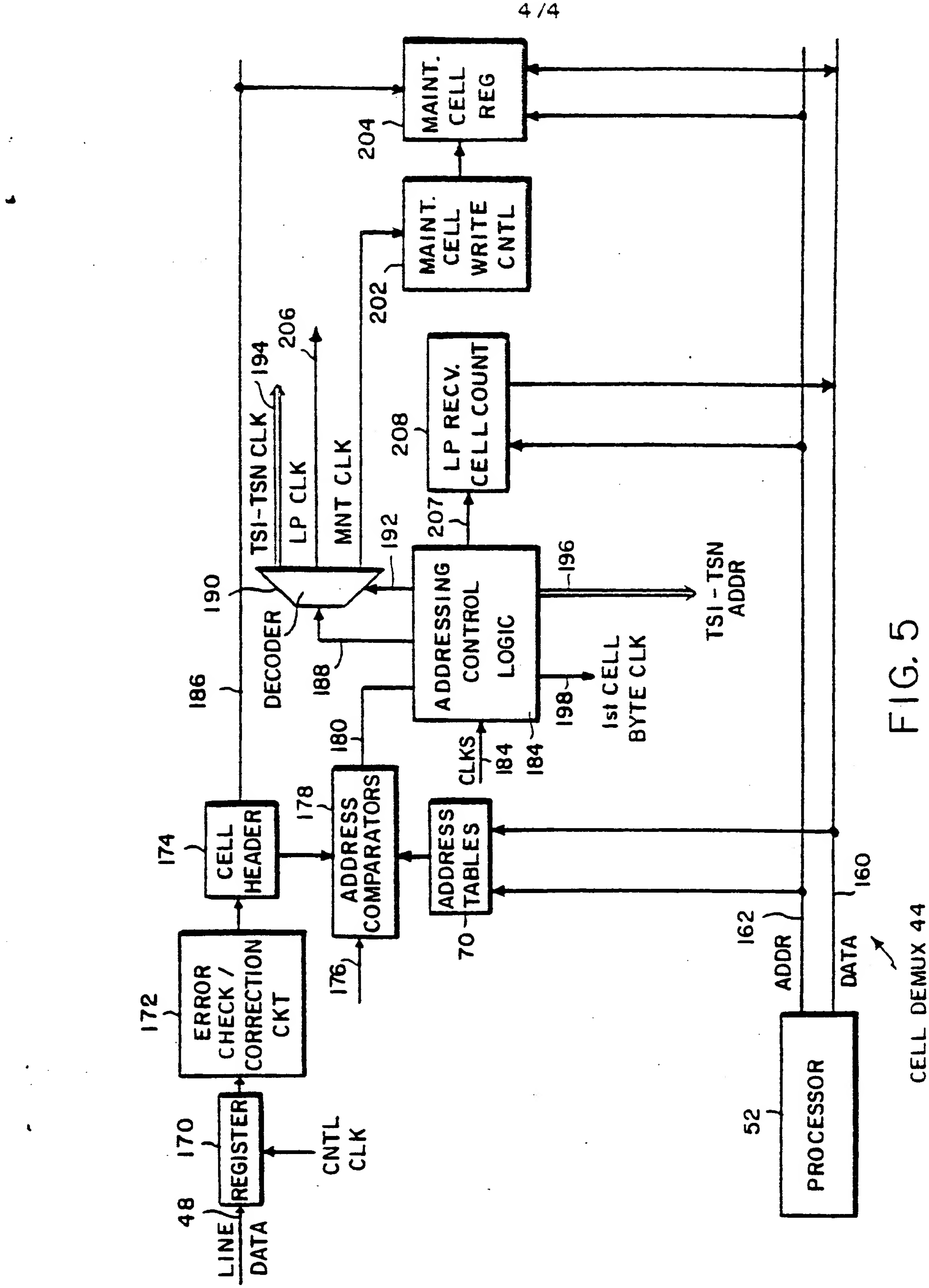
LINE CLK
MUX
TSI - TSN DATA
MAINT. CELL READ CNTL
IDLE CELL READ CNTL
IDLE CELL REG
POLLING STATE MACHINE
LINE CLK
LP CLK
TSI-TSN CLK
MNT CLK
IDL CLK
MNT CLK
IDL CLK
MAINT. CELL REG.
TSI - TSN RDY
MAINT. RDY
LP CELL CNT
FIFO MEMORY
DATA 92
ADDR 94
W
R
MEMORY CONTROL
CELL DISCARD COUNT
CELL CREDIT COUNTER
CELL CREDIT REGISTER
≠0
LOAD
PROG. DIV.
CELL CLK
LP DATA
IN CLK
LP CLK
CELL HEADER
ADDR COMP
ADDR TABLE
CELL FILTER & PEAK RATE POLICING CONTROL
INTERCELL COUNT
ERROR DETECTION/ CORRECT CKT
LP DATA
PRO- CESSOR
ADDER
DATA
ADDRESS ERROR COUNT
PEAK POLICING DISCARD COUNT
CELL MUX 42

FIG. 4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REGISTER
170
CNTL CLK
ERROR CHECK / CORRECTION CKT
172
CELL HEADER
174
ADDRESS COMPARATORS
178
176
ADDRESS TABLES
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180
ADDRESSING CONTROL LOGIC
CLKS
184
184
198
1st CELL BYTE CLK
196
TSI - TSN ADDR
188
DECODER
190
186
192
TSI-TSN CLK
194
LP CLK
206
MNT CLK
207
LP RECV. CELL COUNT
208
MAINT. CELL WRITE CNTL
202
MAINT. CELL REG
204
PROCESSOR
52
ADDR
162
DATA
160
CELL DEMUX 44

FIG. 5